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A set of time varying television test patterns

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THE BRITISH BROADCASTING CORPORATION

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Summary

The zone plate is now established as a powerful diagnostic tool in the study of television processing systems. This Report introduces the time variable, resulting in a family of related patterns which still further increase the usefulness of this approach. These patterns can readily be generated electronically and an indication of the method is given.

Issued under the authority of

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BRITISH BROADCASTING CORPORATION

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A SET OF TIME VARYING TELEVISION TEST PATTERNS

M. Weston, B.A.

1. Introduction

This Report describes a set of test patterns which can be used to display the amplitude/frequency characteristics of television systems horizontally, vertically and temporally. The more familiar test signals such as line sweep, multiburst or test card resolution bars consist of stationary vertical gratings. Although they can reveal a great deal about simple one-dimensional television systems such as filters, cables and amplifiers, they cannot show the effects produced by more sophisticated systems which combine signals from different scan lines or pictures (e.g. vertical aperture correctors, comb filter coders, sub-Nyquist sampling systems, noise reducers and standards converters). These systems must be investigated using patterns which change from line to line or from picture to picture.

BBC Research Department has investigated such systems using gratings which could be adjusted to any pitch, slope and speed of motion. However, since only one pattern could be produced at a time, a thorough investigation of a complex system such as a standards converter was an extremely time consuming process. This situation is eased for stationary patterns by the use of a two-dimensional frequency sweep called the circular zone plate.[1] This contains all possible spatial frequencies at all possible slopes but it was until recently only available as an optical test card from which inevitably imperfect signals were obtained by means of a television camera or slide scanner.

In order to give higher quality test signals an alternative two-dimensional frequency sweep pattern called the hyperbolic zone plate[1] (or Girard Grille[2]) was generated electronically (digitally). This pattern, although more easily generated, is however slightly less easy to interpret than the circular zone plate, and the lack of movement limits the usefulness of both patterns.

A new electronic (digital) pattern generator has now been built, which can produce not only stationary patterns such as hyperbolic and circular zone plates, but also moving patterns and even sweeps of the temporal frequency component as well as of the two spatial frequency components. This Report illustrates the patterns which can be produced, gives some examples of their use and describes briefly how they can be generated.

2. Principles

It is convenient to describe sinusoidal gratings by specifying the phase of the sine wave at each point in the picture. This Report describes the set of patterns corresponding to a phase ϕ varying from point to point and from picture to picture according to the general second-degree equation in x, y and t:

$$\begin{aligned}\phi = k_\phi \quad & + k_x.x \quad + k_y.y \quad + k_t.t \\ & + k_{yt}.y.t \quad + k_{xt}.x.t \quad + k_{xy}.x.y \\ & + \tfrac{1}{2}k_{x^2}.x^2 + \tfrac{1}{2}k_{y^2}.y^2 + \tfrac{1}{2}k_{t^2}.t^2 \qquad (1)\end{aligned}$$

[where x is the horizontal displacement from a specified origin

y is the vertical displacement from the origin

and t is elapsed time]

Any spatio-temporal frequency can be resolved into three frequency components; horizontal, vertical and temporal. The horizontal component is the rate of change of phase in the horizontal direction:

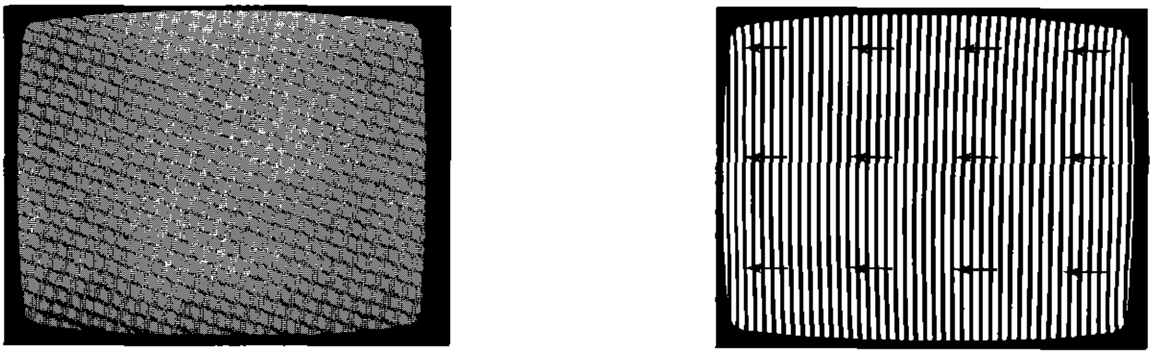
$$\frac{\partial\phi}{\partial x} = k_x + k_{x^2}.x + k_{xy}.y + k_{xt}.t \qquad (2)$$

thus k_x controls the horizontal frequency component at the origin and k_{x^2}, k_{xy} and k_{xt} control the rates at which this component of the frequency varies with horizontal and vertical position and with time.

Similarly, the vertical frequency component is:

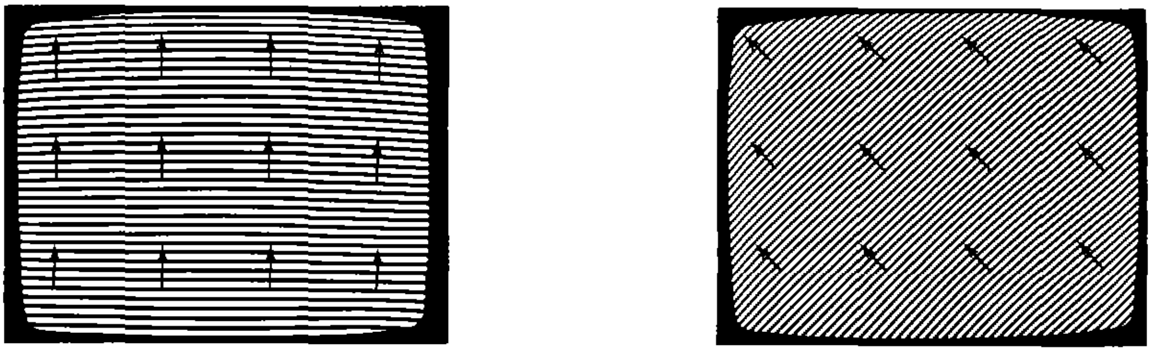
$$\frac{\partial\phi}{\partial y} = k_y + k_{xy}.x + k_{y^2}.y + k_{yt}.t \qquad (3)$$

and the temporal frequency component is:



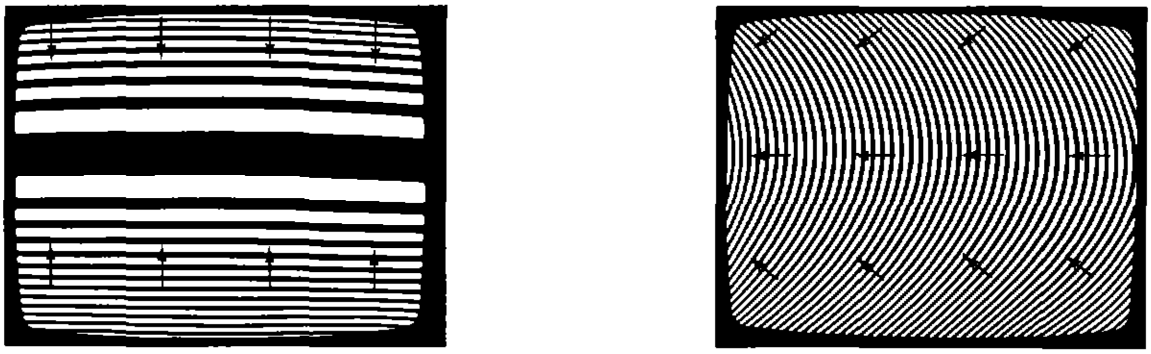
(a) Time terms only

(b) x and time terms



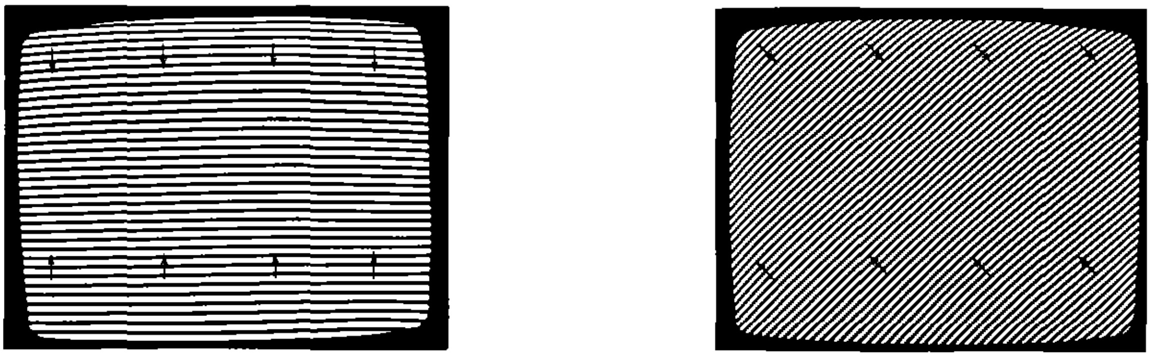
(e) y and time terms

(f) x, y and time terms



(i) y^2 and time terms

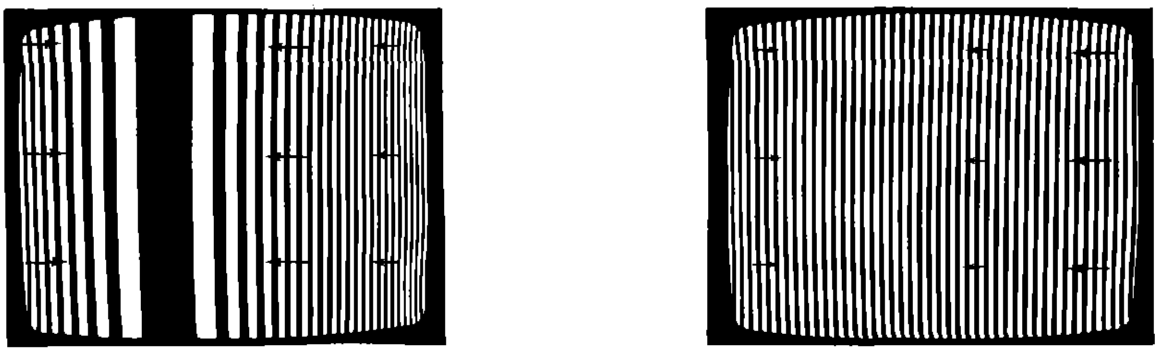
(j) x, y^2 and time terms



(m) $y.t$ term only

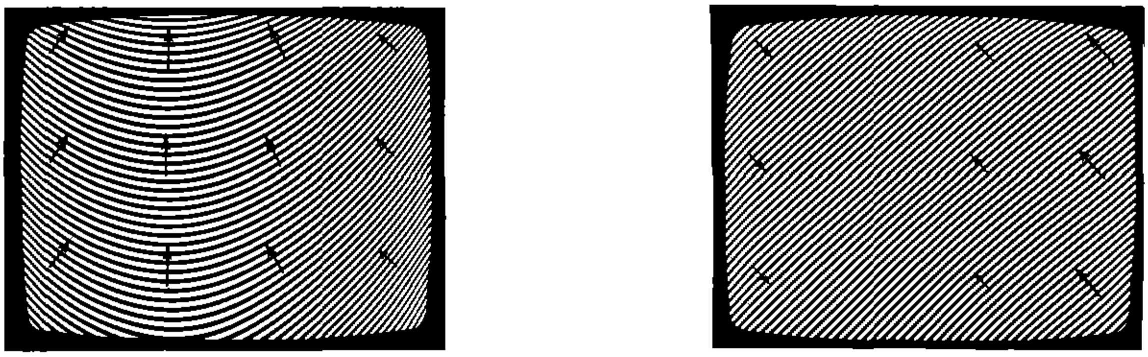
(n) x and $y.t$ terms

Fig. 1 - A matrix of useful patterns



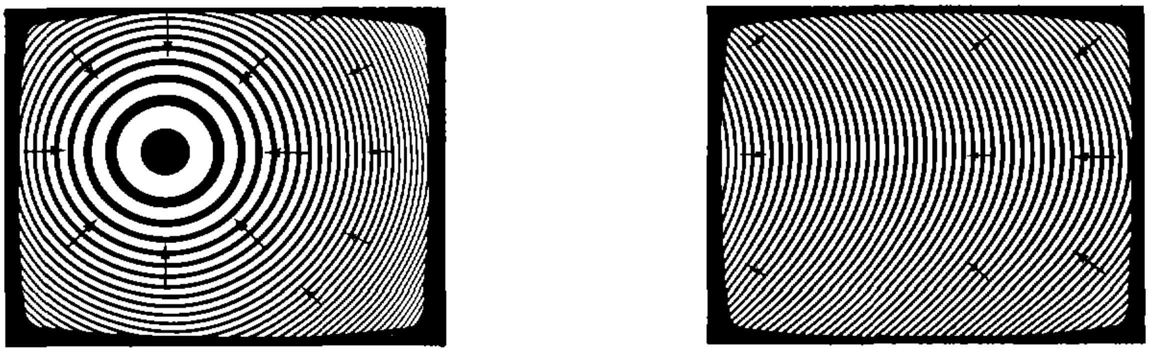
(*c*) x^2 and time terms

(*d*) $x.t$ term only



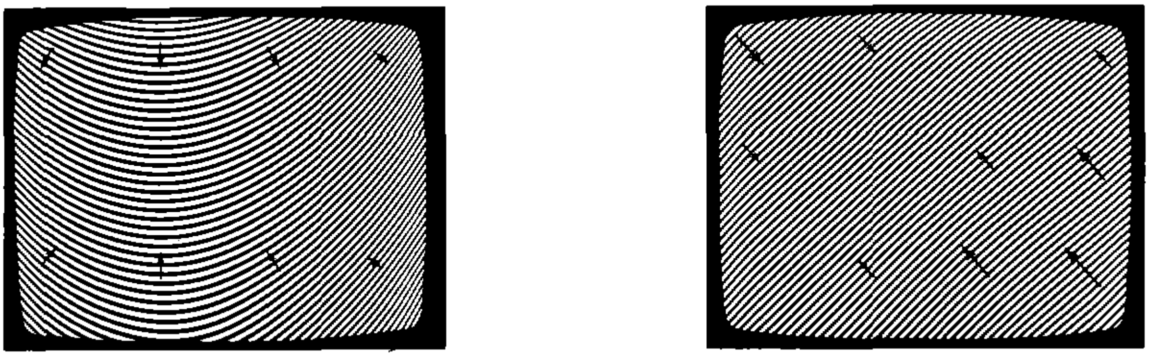
(*g*) x^2, y and time terms

(*h*) $x.t$ and y terms



(*k*) x^2, y^2 and time terms*

(*l*) $x.t$ and y^2 terms



(*o*) x^2 and $y.t$ terms

(*p*) $x.t$ and $y.t$ terms

Fig. 1 - A matrix of useful patterns
*[x^2 and y^2 coefficients of some polarity]

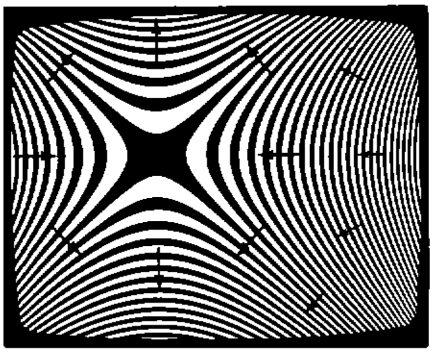
$$\frac{\partial\phi}{\partial t} = k_t + k_{xt}.x + k_{yt}.y + k_{t2}.t \qquad (4)$$

So vertical and temporal frequency components can also be made to vary with position and time. Note, however, that these three equations are not completely independent. For example, the horizontal component $\partial\phi/\partial x$ and the vertical component $\partial\phi/\partial y$ are both functions of k_{xy} which thus controls both the vertical variation of the horizontal frequency component and the horizontal variation of the vertical frequency component. Similarly k_{xt} controls both the horizontal variation of the temporal component $\partial\phi/\partial t$ and the temporal variation of horizontal component $\partial\phi/\partial x$. And, k_{yt} controls both the vertical variation of the temporal component and the temporal variation of the vertical component.

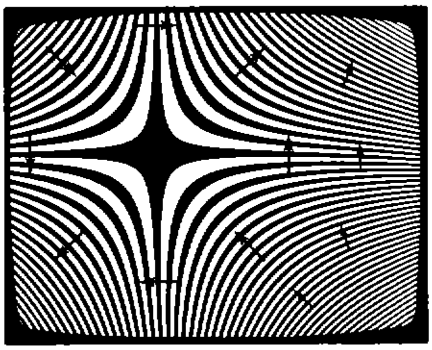
If the patterns are generated electronically as a television signal, the smallest increment of t is one field period and the smallest increment of y is one line spacing. If the patterns are generated digitally as a sampled signal, the smallest increment of x is equal to the horizontal sampling pitch. Because of these restrictions the three frequency components cannot rise indefinitely. A frequency called the 'Nyquist limit' is reached where the phase changes by more than half a cycle between successive fields, lines or sampling points. This is the same as changing the phase by less than half a cycle in the opposite direction so that, instead of continuing to rise, the frequency decreases steadily back to zero and the pattern repeats. For a 625 line/50 Hz television signal sampled 851 times per line the maximum frequency components are: temporally 25 Hz, vertically 312½ cycles per picture* height and horizontally 425½ cycles per picture* width (or 6.65 MHz).

3. Useful patterns

Indiscriminate use of the ten coefficients in Equation (1) would produce an almost limitless range of possible patterns. In the prototype generator each of the coefficients is controlled by a sixteen position switch, which gives a total of more than 10^{12} possible combinations. Fortunately, the most useful patterns have most of the coefficients equal to zero, so that each of the three frequency components is either zero, fixed or a function of only one of the three variables (x, y or t). Fig. 1 illustrates 16 of these restricted patterns. They are arranged in a matrix in which the horizontal frequency component is zero for the left hand column of photographs, fixed for the next column, proportional to x for the third column and proportional to t for the right hand column. Similarly the vertical frequency component is zero in the top row, fixed in the next row, proportional to y in the third row and proportional to t in the bottom row. Two very important patterns which do not fit into this matrix are illustrated in Fig. 2.



(*a*) x^2, y^2 and time terms*



(*b*) $x.y$ and time terms

Fig. 2 - Two other useful patterns (Hyperbolic zone plates)

* [x^2 and y^2 coefficients of opposite polarity]

The patterns in the right hand column and in the bottom row are inherently moving since their properties are functions of t. The other nine patterns can be made to move by adding the time terms $k_t.t$ or $\frac{1}{2}k_{t2}.t^2$. The direction and speed of movement is indicated by arrows of length proportional to speed, drawn on the photographs. These photographs are intended to illustrate the basic properties of three dimensional frequencies and frequency sweeps. So for clarity, the spatial frequencies have been kept low. Much higher frequencies would be used for most real applications as illustrated in Section 4.

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* For the purpose of defining these units the line and field blanking intervals are included as part of the picture.

3.1. Constant spatio-temporal frequencies

Figs. 1(*a*), (*b*), (*e*) and (*f*) are patterns of fixed pitch slope and speed produced by combinations of the terms $k_t.t$, $k_y.y$ and $k_x.x$. Each pattern consists of one particular spatio-temporal frequency.

Fig. 1(*a*) consists of a blank picture whose brightness pulsates at a rate proportional to k_t. Adding a finite amount of $k_x.x$ to the equation produces a regular vertical grating (Fig. 1(*b*)) whose spatial frequency is proportional to k_x. If $k_t = 0$ the pattern is stationary, but if k_t is finite the pattern moves at a uniform rate as shown by the arrows.

Similarly, the term $k_y.y$ produces a regular horizontal grating (Fig. 1(*e*)) moving at a uniform rate dependent on k_t. Combining $k_x.x$ and $k_y.y$ produces sloping patterns as shown in Fig. 1(*f*). The slope depends on the ratio of $k_x:k_y$. The spatial frequency is proportional to $(k_x{}^2 + k_y{}^2)^{1/2}$.

By adjusting k_x, k_y and k_t it is possible to produce any combination of horizontal, vertical and temporal frequency. As indicated in Section 1, equipment to generate such patterns was produced at BBC Research Department several years ago. It proved to be very time consuming to examine the response of a system to all possible spatio-temporal frequencies one by one. So the need to present all the frequencies in a single display was recognised.

3.2. Spatial frequency sweeps

Fig. 1(*c*) is a familiar one-dimensional sweep of horizontal frequency known as 'line sweep'. The horizontal frequency component is proportional to the horizontal displacement from an origin.

Fig. 1(*i*) is a similar one-dimensional sweep of vertical frequency.

Diagonal patterns can be obtained by adding vertical frequency components to the horizontal sweep to give Fig. 1(*g*), or horizontal components to the vertical sweep to give Fig. 1(*j*), or by combining horizontal and vertical frequency sweeps into a two-dimensional frequency sweep.

Fig. 1(*k*) is a two-dimensional frequency sweep known as the circular zone plate in which the horizontal frequency component is proportional to horizontal displacement from the centre of the circles and the vertical frequency component is proportional to the vertical displacement. This pattern contains all possible slopes of pattern, horizontal, vertical and diagonal, with a range of pitches depending on the sweep rates k_{x2} and k_{y2}. If k_{x2} and k_{y2} are not equal, an elliptical pattern is obtained.

Fig. 2(*a*) shows a very closely related pattern produced by changing the sign of the $k_{y2}.y^2$ term. This changes the circles into hyperbolas, but does not change the spectral properties of the pattern. Horizontal frequency is still proportional to horizontal displacement and vertical frequency to vertical displacement. The overall spatial frequency is also still proportional to the distance from the centre of the pattern (i.e. the origin). So it is constant on any circle centred on the origin, although the pattern itself does not have circular symmetry.

Rotating Fig. 2(*a*) by 45° gives Fig. 2(*b*) which is also a two-dimensional frequency sweep but with horizontal and vertical axes interchanged. In this case, the horizontal frequency component is proportional to vertical displacement and the *vertical frequency component is proportional to* horizontal displacement from the origin. This has the simple phase function $\phi = k_{xy}.xy$.

Because of its much simpler phase function this was the first two dimensional frequency sweep to be generated electronically at BBC Research Department.[1] However, because of its more obvious symmetry the circular zone plate is much easier to interpret and tends to be preferred now that it too has been generated electronically.

Up to this point only stationary frequency sweeps have been considered. They may be made to move by adding the term $k_t.t$ to the phase equation and thus adding a constant temporal frequency component to the patterns. This makes the patterns move as shown by the arrows. Note that although the patterns move they do not change their form or spatial properties. The brightness of each point in the picture oscillates at the same frequency (k_t) so that after one period of oscillation the pattern repeats identically. Each line moves to replace its neighbour. To achieve this the finer parts of the pattern which do not have so far to move, travel more slowly across the picture. If the entire pattern were to move at the same velocity the finer parts of the pattern would have a higher temporal frequency.

3.3. Accelerating patterns

All of the patterns described so far have been either stationary or moving with a fixed temporal frequency of k_t. The term $½k_{t2}.t^2$ makes the temporal frequency proportional to time. The repetition rate increases steadily from stationary up to 25 Hz. At 25 Hz the phase change between successive fields is 180°. Beyond this point, the direction of motion changes and the frequency decreases steadily back to stationary and the cycle repeats over and over again.

Adding the term $½k_{t2}.t^2$ to the circular zone plate gives:

$$\phi = ½k_{x2}.x^2 + ½k_{y2}.y^2 + ½k_{t2}.t^2$$

which is a truly three-dimensional frequency sweep which has been named the 'spherical zone plate' (although the third dimension is time and not space). Each picture contains all possible spatial frequencies and periodically all possible rates of movement are presented.

3.4. Temporal frequency plots

Although the accelerating patterns described in the previous section present all possible temporal frequencies, they do so sequentially. In many applications in which temporal frequency is of interest (e.g. standards conversion) it would be more useful to plot temporal frequencies along the x or y axis so that all temporal frequencies are simultaneously available for comparision. This may be achieved by using the terms $k_{xt}.xt$ or $k_{yt}.yt$.

The term $k_{xt}.xt$ makes the temporal frequency proportional to the horizontal position as illustrated by the arrows in Fig. 1(*d*). The pattern was photographed at the instant when it was identical to Fig. 1(*b*). But whereas Fig. 1(*b*) does not change its form as it moves, the lines of Fig. 1(*d*) converge on each other altering the pitch of the pattern. The horizontal frequency component thus increases continuously until it reaches half a cycle per sample. The direction of motion then reverses, the frequency decreases, passes through zero and the sequence repeats over and over again. Throughout this sequence of events the temporal frequency remains a fixed linear function of horizontal frequency. Temporal frequency is thus plotted along the x-axis although the picture itself is continuously changing.

Fig. 1(*d*) contains no vertical frequency component. Fig. 1(*b*) has a fixed vertical frequency component added. At $t = 0$ the pattern is identical to Fig. 1(*e*), but as t increases the pattern rotates as the horizontal frequency component increases. At the instant of the photograph it is identical to Fig. 1(*f*), but it then continues to rotate as the horizontal frequency increases still further until it reaches half a cycle per sample, and decreases back to zero and so on.

Fig. 1(*l*) combines a horizontal sweep of temporal frequency with a vertical sweep of the vertical frequency component. It thus plots vertical and temporal frequency components along the vertical and horizontal axes respectively. This is particularly useful for studying the vertical and temporal interpolation of field store standards converters. As before, the horizontal frequency component is continuously changing with time, which is something of an inconvenience, but it has not yet been possible to devise a pattern in which this is not the case. Figs. 1(*m*), (*n*) and (*o*) are similar to (*d*), (*g*) and (*l*), but with the horizontal and vertical dimensions interchanged. Fig. 1(*p*) completes the matrix of photographs by combining the $x.t$ and $y.t$ terms.

4. Applications

The previous section illustrated the basic properties of the patterns in terms of relatively low frequencies. This section outlines the use of some patterns containing much higher frequencies to study real relevision systems under investigation in BBC Research Department.

Fig. 3(*a*) shows a circular zone plate with much higher sweep rates than used for Fig. 1(*k*). The horizontal frequency sweep extends from more than 5.5 MHz at the left of the picture, through zero in the centre, to more than 5.5 MHz at the right. The dark, featureless bands at left and right are caused by a low-pass filter removing all patterns with horizontal frequency components above 5.5 MHz. As the horizontal sweep passes the Nyquist limit of the horizontal sampling, the first repeats of the pattern are just visible at the sides of the picture.

The vertical frequency sweep extends from 312½ cycles/picture height at the top, through zero in the centre to approximately 312½ cycles/picture height at the bottom. The fainter circular patterns at the top and bottom of the picture are due to the 625 line interlaced scanning system. In trying to display 312½ cycles/picture height it produces one field of black and the interlaced field of white. This is seen as a low frequency pattern

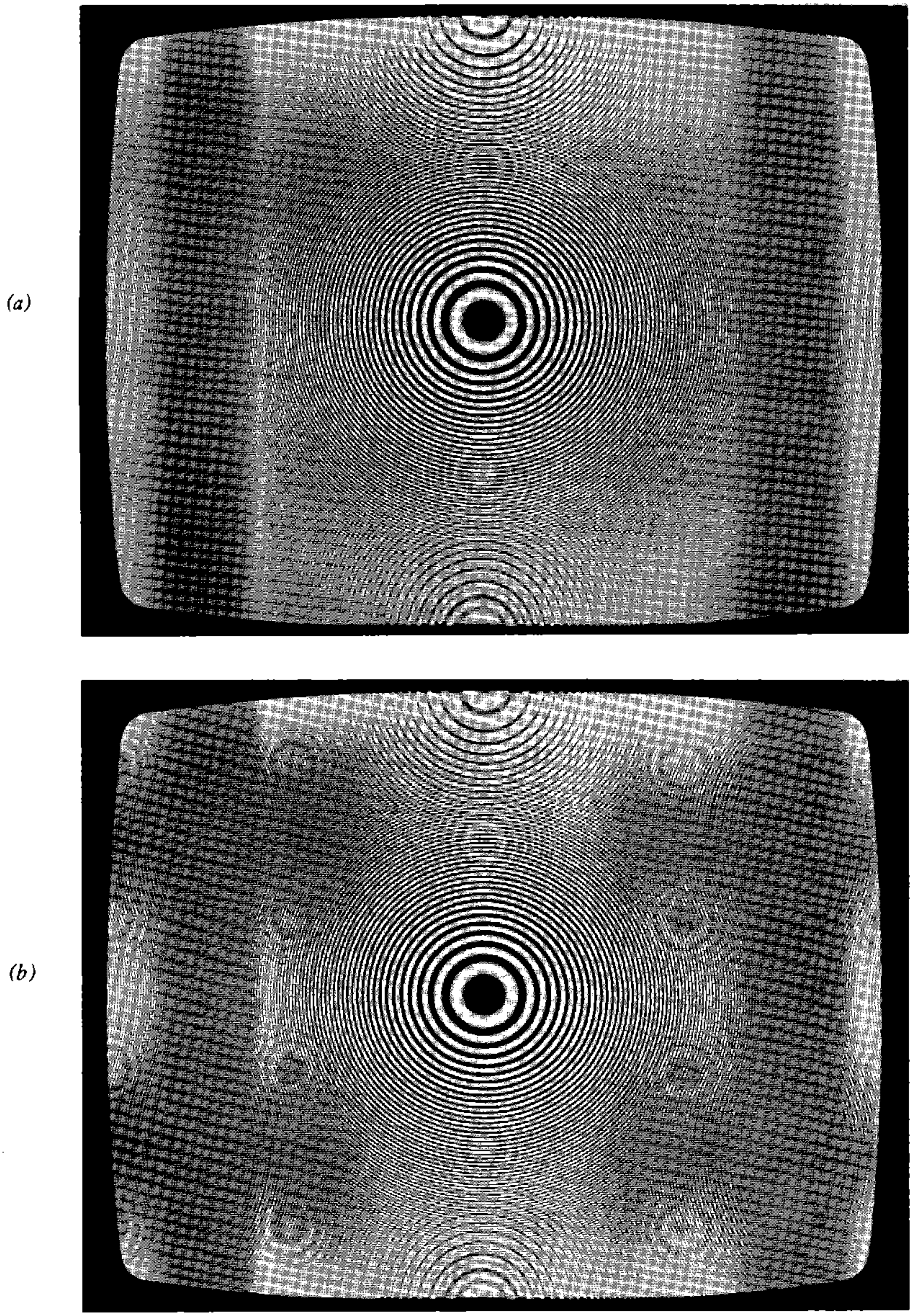


Fig. 3 - High spatial frequency circular zone plate

(a) direct (b) via sub-Nyquist sampling system flickering at 25 Hz. Even photographing the pattern with a two field exposure does not completely remove this effect. Because of the non-linearity (gamma) of the display tube, areas which are flickering between black and white have a greater average brightness than nearby areas which are not flickering. A two field exposure thus leaves the faint residual patterns shown.

The effects so far described are those which are inherent in any interlaced television system with a restricted video bandwidth. Fig. 3(*b*) shows the additional effect produced by passing the analogue output of the pattern generator through a sub-Nyquist sampling system,[3] such as might be used for digital transmission of television signals. The faint circular patterns are caused by alias components (generated by sub-Nyquist sampling) beating with the incoming signal to produce a low-frequency pattern. The extra darkened areas show the loss of diagonal detail caused by the comb filters used to try to reduce the effects of aliasing. Conventional test signals, such as line sweep, multiburst or test card resolution bars, would have revealed neither of these effects.

Fig. 4(*a*) shows a pattern which plots the temporal frequency component horizontally and the vertical frequency component vertically. The horizontal frequency component is varying with time as discussed in Section 3.4. The centre of the pattern is stationary and has zero vertical frequency component. Above and below the centre the vertical frequency component increases up to 312½ cycles/picture height. To the left and right of the centre the temporal frequency component increases up to 25 Hz in either direction. Because of the interlaced 625 line/50 Hz scanning system the pattern repeats centred on the corners of the screen.

In converting from the 625 line/50 Hz scanning standard to the 525/60 Hz standard it is necessary to interpolate between lines and fields of the input standard to generate new lines and fields on the output standard. This interpolation may be considered as a two dimensional filtering process, to remove the high order spectra of the input standard, followed by a resampling on the output standard. The performance of the two dimensional filtering process can be displayed using the pattern of Fig. 4(*a*).

Fig. 4(*b*) shows the result of passing the test pattern through a standards converter in which the filtering action of the interpolator has been deliberately made very severe to show the effect of removing a very large proportion of the spatio-temporal spectrum. The photo shows clearly the diamond shaped spectrum remaining around each of the stationary low frequency points. One object of the present work in standards conversion is to make these areas as large as possible without allowing them to overlap too much, since this produces undesirable beat patterns.

5. Instrumentation

5.1. Phase computation

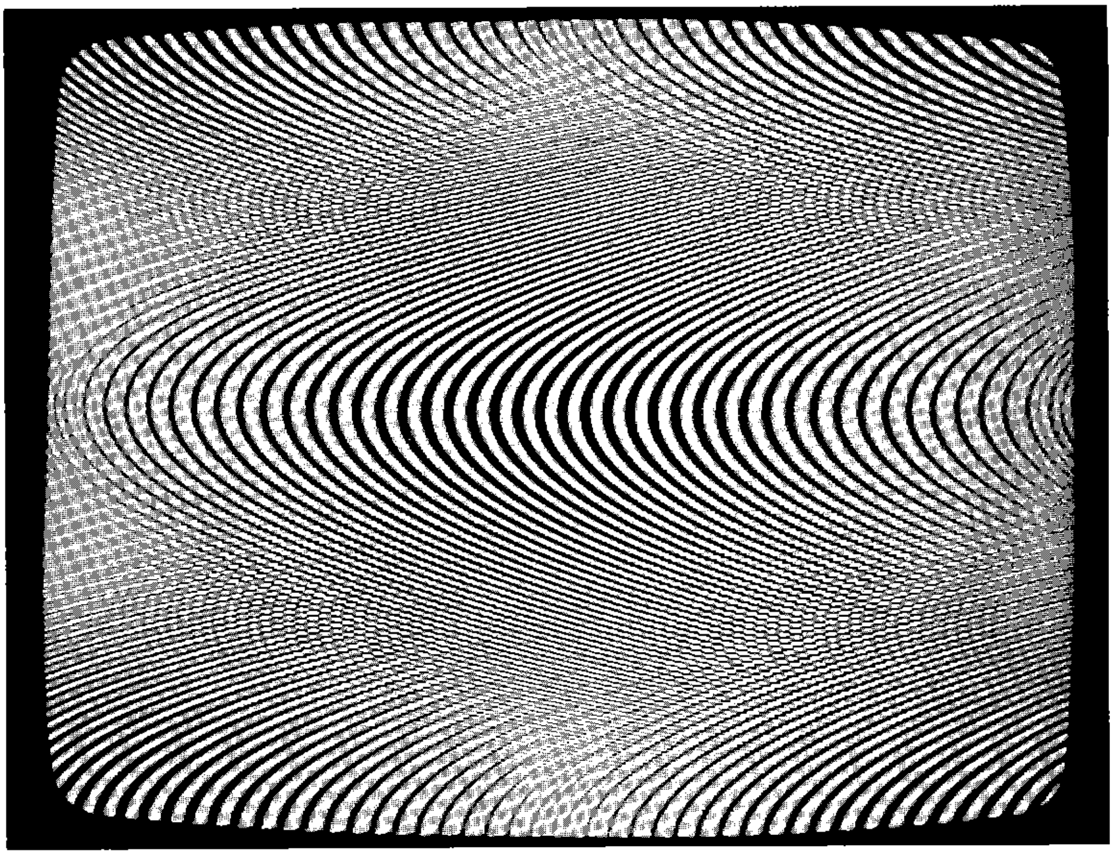
In order to generate the required patterns, the generator must calculate the phase ϕ according to Equation (1) for each sampling point in the picture. If the sampling frequency is line locked so that the sampling points are vertically aligned, then x can be defined as the number of samples from the left-hand side of the picture, y can be defined as the number of lines from the top of the picture and t as the number of fields since last reset by the operator. Because of interlace, y increases each line in steps of two so that for one of the two interlaced fields y is even and for the other field y is odd. (Assigning a fixed value of y to the whole of each scanning line and a fixed value of t to the whole of each field is an admissible simplification.)

The values of x, y and t for each sample could be generated by element, line and field rate counters and the phase ϕ calculated by multiplication and addition according to Equation (1). Multiplication is one of the most difficult operations to perform, so the prototype generator avoids the use of multipliers by generating each of the terms in Equation (1) using accumulators as shown in Fig. 5.

The number $k_t.t$ increases each field during field blanking by the amount k_t. It can thus be generated by an accumulation circuit which stores the present value of $k_t.t$ and adds k_t to it during each field blanking period. Similarly $k_y.y$ can be generated by an accumulator which stores the present value and adds $2.k_y$ to it during each line blanking period, the accumulator being reset at the top of each picture to values differing by k_y on odd and even fields. Similarly, $k_x.x$ is generated by an accumulator which adds k_x once per sample and is reset at the beginning of each line.

Generating the three 'cross-product' terms ($k_{xy}.x.y$, $k_{yt}.y.t$ and $k_{xt}.x.t$) is a two stage pro-

(a)



(b)

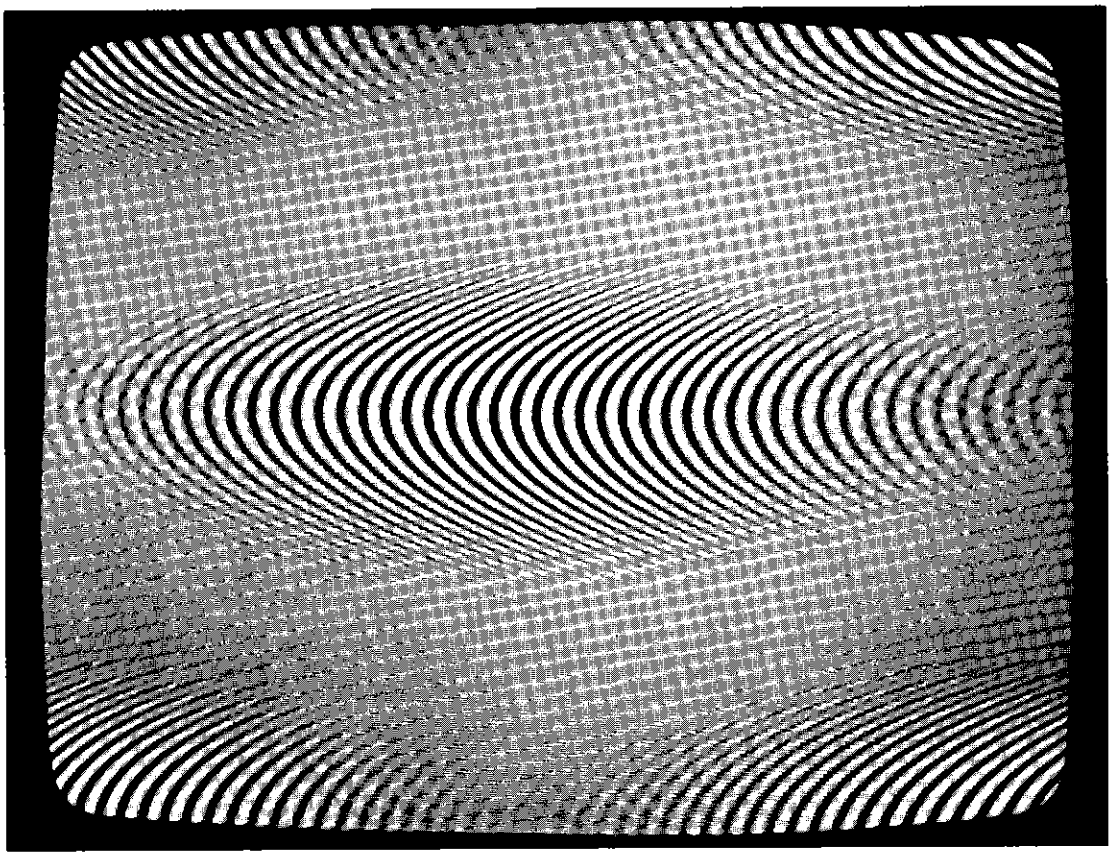


Fig. 4 - Horizontal sweep of temporal frequency component combined with vertical sweep of vertical frequency component

(a) Direct 625 line/50 Hz (b) Converted to 525 line/60 Hz (exaggerated filtering)

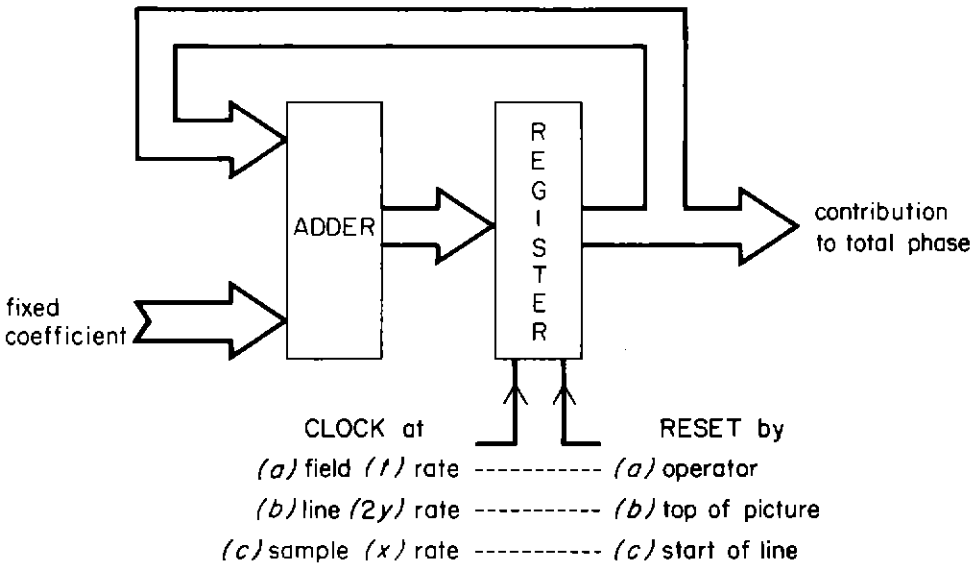


Fig. 5 - A basic accumulator circuit

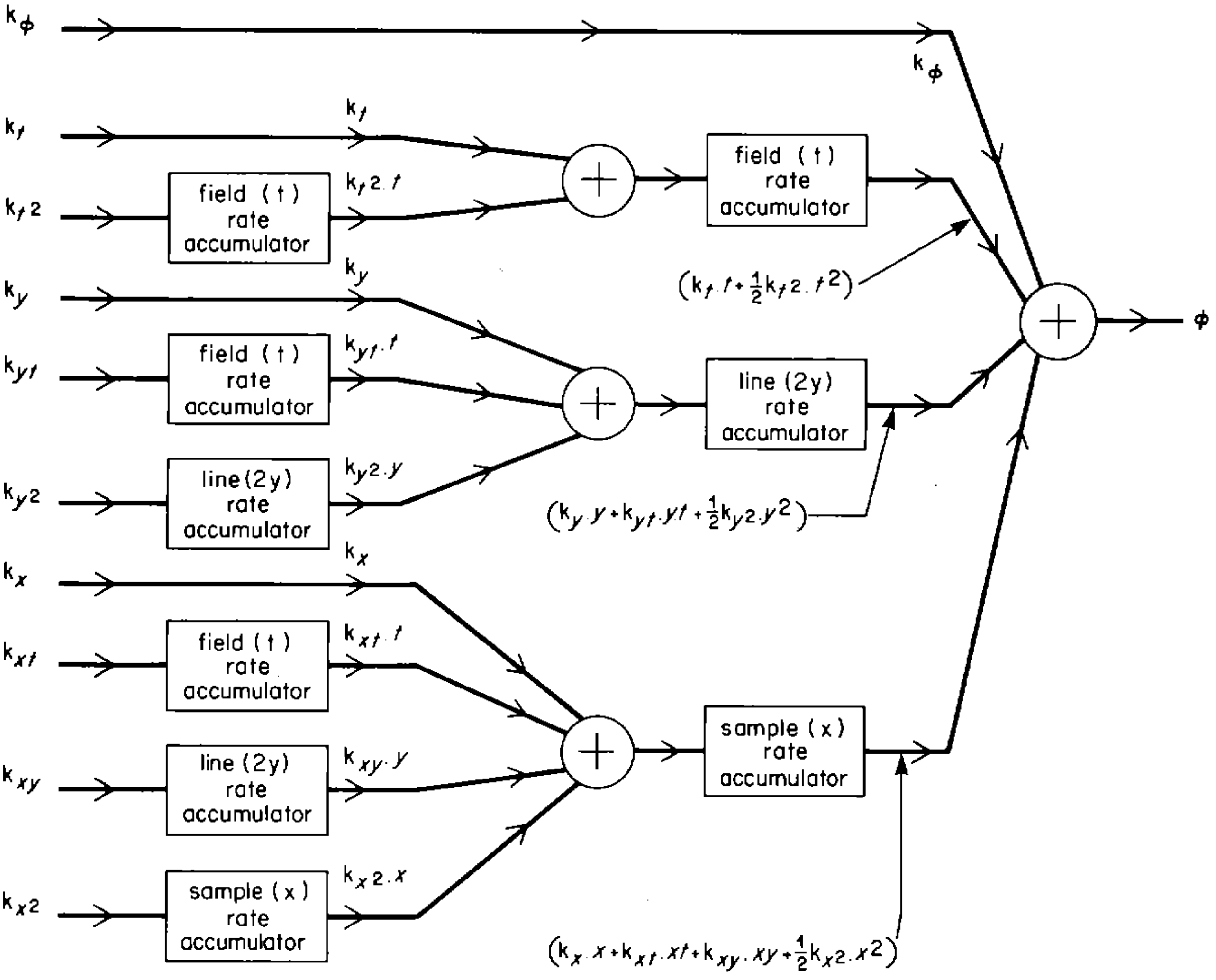

k_ϕ
k_t
k_{t2}
k_y
k_{yt}
k_{y2}
k_x
k_{xt}
k_{xy}
k_{x2}
field (t) rate accumulator
line (2y) rate accumulator
sample (x) rate accumulator
k_t
$k_{t2}.t$
k_y
$k_{yt}.t$
$k_{y2}.y$
k_x
$k_{xt}.t$
$k_{xy}.y$
$k_{x2}.x$
k_ϕ
$(k_t.t+\frac{1}{2}k_{t2}.t^2)$
$(k_y.y+k_{yt}.yt+\frac{1}{2}k_{y2}.y^2)$
$(k_x.x+k_{xt}.xt+k_{xy}.xy+\frac{1}{2}k_{x2}.x^2)$
ϕ

Fig. 6 - Arrangement of nine accumulators to compute Equation (1)

cess. For example, $k_{xy}.x.y$ is a number which increases each sample by $k_{xy}.y$, which itself is a number which increases by $2k_{xy}$ for each line of the field. The term $k_{xy}.x.y$ can thus be generated by a sample rate accumulator which is reset at the beginning of each line and then, for each sample, adds the output of a line rate accumulator which is reset at the beginning of each field. The terms $k_{yt}.y.t$ and $k_{xt}.x.t$ are generated in a similar manner.

The 'squared' terms are also generated by a two stage process. For example $\frac{1}{2}k_{x^2}.x^2$ increases each sample by $(k_{x^2}.x - \frac{1}{2}k_{x^2})$ which itself increases each sample by k_{x^2}. $\frac{1}{2}k_{x^2}.x^2$ is thus generated by two element-rate accumulators in tandem.

As the accumulations continue the phase will go through many complete cycles, but since only the fractional part is required to generate sine waves, the accumulators need only count fractions of a cycle and can be allowed to overflow after each complete cycle.

If each of the terms were generated separately, a total of 15 accumulators would be required, one for each of the three first order terms in x, y and t, and two for each of the six second order terms in yt, xt, xy, x^2, y^2 and t^2. It is however possible to combine the operations as shown in Fig. 6 so that only nine accumulators are required. A microprocessor could perform the four field-rate and three line-rate accumulations, leaving only two element-rate accumulations to be performed by dedicated high speed arithmetic circuits.

5.2. Waveform synthesis

Having calculated the phase of each point it is then necessary to convert this to an output signal of the required waveshape. If the phase number were used directly as the video output (either as a digital signal or through a digital to analogue converter) then the sawtooth waveform shown in Fig. 7(*a*), would be produced. This waveform contains a large number of harmonics and is thus not suitable for measuring amplitude/frequency characteristics. A better (although still not perfect) waveform is the triangular wave shown in Fig. 7(*b*). This can be obtained from the sawtooth phase signal by doubling the gain and inverting the top half of the signal. Fig. 7(*c*) shows the square wave produced by feeding the most significant bit of the triangular wave to all output bits. This maximises the harmonic content.

The only way to produce an output free of harmonics is to generate a sine wave as in Fig. 7(*d*). This can be achieved by a Read Only Memory (ROM) programmed with the values of sin ϕ for each value of ϕ that the generator can produce. In practice, only half a cycle of sine wave is stored in the ROM and its input is addressed by the triangular wave.

A sine wave may eventually be distorted by the non-linearity of the display tube. So for some applications, it is useful to generate precorrected sine waves as shown in Fig. 7(*e*) using another ROM. Other ROMs can be programmed to generate any other useful waveshapes.

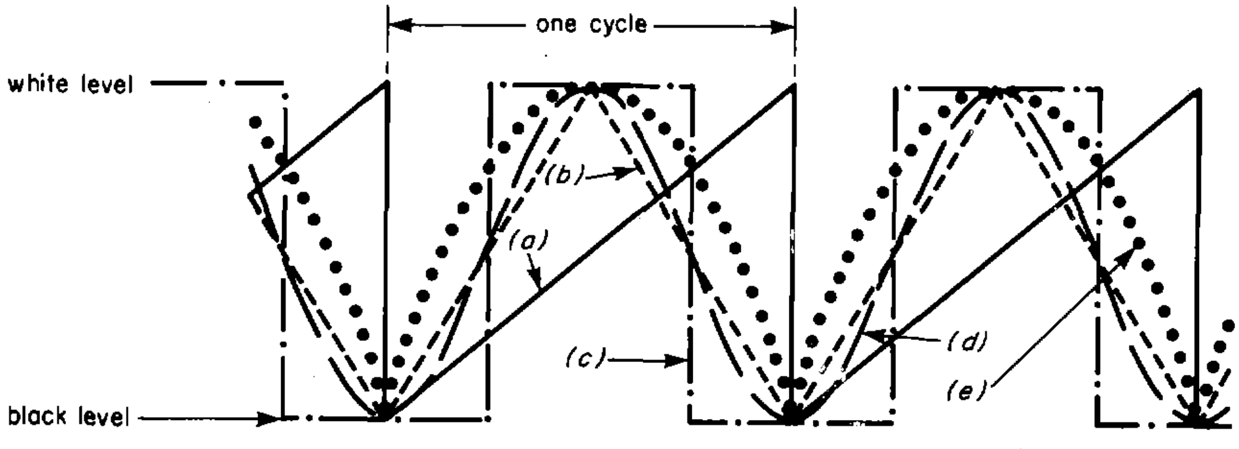


Fig. 7 - Output waveshapes

(*a*) ——— Sawtooth (*b*) - - - - - - Triangular wave (*c*) —·— Square wave (*d*) — — Sine wave

(*e*) • • • • • • Sine wave precorrected for display (γ = 2.5)

6. Conclusions

The set of test patterns corresponding to phase varying according to the general second degree equation in x, y and t contains some extremely useful patterns for rapidly displaying the amplitude/frequency characteristics of television systems in up to three dimensions. This report has illustrated the most useful patterns, giving some examples of their use and describing how they may be generated digitally. It is now the subject of a licencing arrangement with an outside manufacturer* who plans to have equipment available soon.

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* V.G. Electronics Ltd.

7. References

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